LPP Source System Development for HVM

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ABSTRACT

Laser produced plasma (LPP) systems have been developed as a viable approach for the EUV scanner light source to support optical imaging of circuit features at sub-22nm and beyond nodes on the ITRS roadmap. This paper provides a review of development progress and productization status for LPP extreme-ultra-violet (EUV) sources with performance goals targeted to meet specific requirements from leading scanner manufacturers. The status of first generation High Volume Manufacturing (HVM) sources in production and of prototype source operation at a leading scanner manufacturer is discussed. The EUV power at intermediate focus is discussed and the lastest data is presented. An electricity consumption model is described, and our current product roadmap is shown.

Keywords: EUV source, EUV lithography, Laser Produced Plasma

1. INTRODUCTION

EUV Lithography is the front runner for next generation critical dimension imaging after 193 nm immersion lithography for layer patterning below the 32 nm node; beginning in 2013 according to the International Technology Roadmap for Semiconductors (ITRS). NAND Flash devices are expected to have the need for this manufacturing technology as soon as 2011, with pilot line system introduction starting this year (2010). The availability of high power 13.5 nm sources has been categorized as high risk and ranked as critical with other technologies requiring significant developments to enable the realization of EUV lithography. High sensitivity photoresists with good line-edge-roughness (LER) and line-width-roughness (LWR) are needed to keep the required source power within reasonable limits. Photoresist sensitivity and overall optical transmission through the EUV scanner are the basis to derive EUV source power requirements within the usable bandwidth (BW) of 2 %. Scanner manufacturers are requiring clean EUV power close to 200W at the intermediate focus (IF) to enable > 100 wph scanner throughput assuming 10 mJ/cm^2 photoresist sensitivity. The need for a spectral purity filter (SPF) increases the requirements for raw EUV Power even higher. Clean EUV Power is calculated by taking the raw EUV power and subtracting the losses associated with the spectral purity filter (SPF) and dose control, for initial sources these losses are estimated to be 35% and 20% respectively. A scalable EUV source architecture is needed to enable the evolution of EUV lithography during the life cycle of the technology. Laser-produced-plasma (LPP) sources are expected to deliver the necessary power for critical-dimension high-volume manufacturing (HVM) scanners for the production of integrated circuits in the post-193 nm immersion era.[1]

LPP EUV lithography light sources generate the required 13.5 nm radiation by focusing a 10.6 micron wavelength CO_2 laser beam into tin (Sn) creating a highly ionized plasma with electron temperatures of several 10's of eV. EUV photons are radiated isotropically by these ions. Photons are collected with a normal-incidence mirror (collector), and focused to an intermediate point from where they are relayed to the scanner optics and ultimately to the wafer. High conversion efficiency (CE) of the laser energy into EUV energy is critical to meeting the required power levels. A prototype configuration based on this approach was shipped to a leading scanner manufacturer in 2009. The normal-incidence mirror is protected from the plasma by hydrogen buffer gas debris mitigation technology. High-energy ions, fast neutrals, and residual source element particles are mitigated to maintain the reflectivity of the collector mirror and enable a long lifetime of this component. Diagnostics measuring the properties of emitted light at both the plasma and IF are

used to characterize the output of the source.[2] Performance results of test and prototype light sources obtained up to about a year ago have already been described in detail previously.[1,3,4,5]

2. LPP SOURCE SYSTEM

The system architecture is show schematically in Figure 1. The three major subsystems of the source are the drive laser, the beam transport system (BTS) and the source vessel. The drive laser is a CO_2 laser with multiple stages of amplification to reach the required power level of ~20 kW.[1,6] It is operated in pulsed mode at ~50 kHz with radio-frequency (RF) pumping from generators (not shown) operating at 13.56 MHz. The laser is typically installed in the sub-fab along with its RF generators and water-to-water heat exchangers. The source controller turns on and off bursts of pulses, which can be as long as several seconds, but is typically 400ms for exposing a 26 x 33mm field size using 10mJ/cm^2 resist. The ratio of time when the burst is on to the burst period defines the duty cycle. The beam is expanded as it leaves the drive laser to maintain the energy density on the BTS mirrors within a certain operating range. Three turning mirrors are used to allow the beam to travel from the sub-fab to the fab through the waffle-slab floor with the needed flexibility for positioning the laser with respect to the source vessel (and scanner) on the floor above. The laser and BTS are completely enclosed and interlocked to meet laser class 1 requirements. The BTS delivers the beam to a focusing optic where the 10.6 micron wavelength light is focused to a minimum spot size defined by the numerical aperture of the focusing system. The focused beam propagates through a central aperture in the collector and strikes the droplet at the focus of the ellipsoidal collector mirror inside the vacuum space of the source vessel chamber. The droplet generator delivers liquid tin droplets of 30 micron diameter to the same position at ~ 50 kHz repetition rate; both laser pulse and droplets are steered and timed to ensure proper targeting. The laser pulse vaporizes and heats the tin into a plasma cloud of critical temperature and density. The EUV light emitted by the plasma is collected and reflected with the multi-layer coated ellipsoidal mirror to the intermediate focus (IF) where it passes through a small aperture into the scanner volume that houses the illumination optics. To ensure that no contamination can reach the scanner volume an IF protection module surrounds the aperture and suppresses flow or diffusion. Other modules on the source vessel include the droplet catcher which collects the unused droplets between the bursts, and metrology modules for measuring EUV energy and for imaging of droplets and plasma.

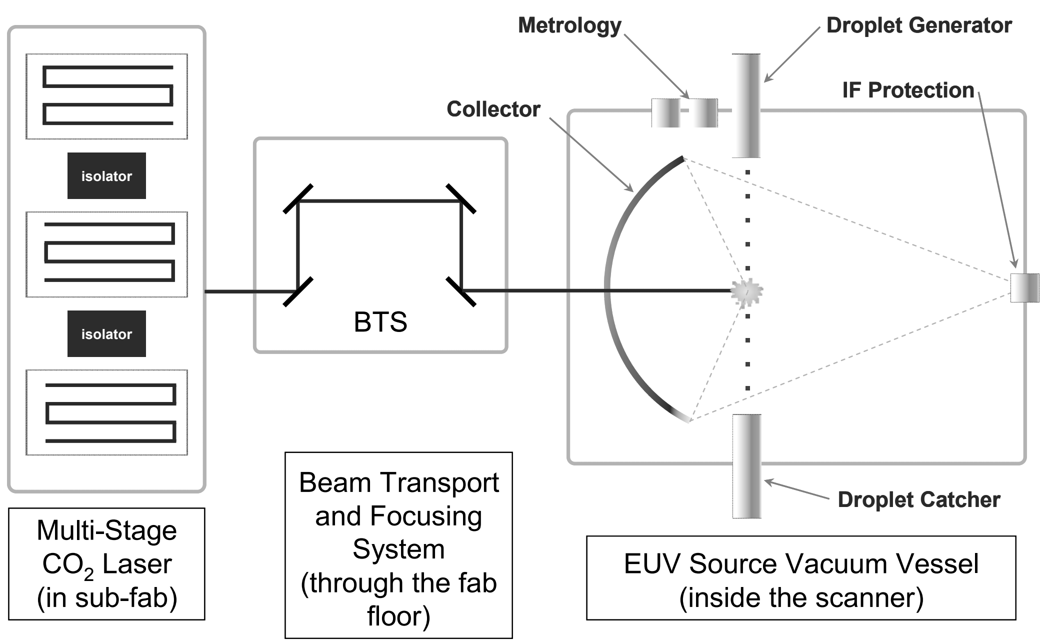

Figure 1: Schematic of Laser Produced Plasma Source.

Six first-generation high-volume manufacturing (HVM I) sources are presently in production in the cleanroom in our San Diego California facility. A source vessel is shown in Figure 2 positioned at specified source orientation angle, and the drive laser for this source is shown in Figure 3. The BTS connects the two major modules through the wall. The first three sources are operational and their performance is being optimizeed to complete acceptance testing for our customers.

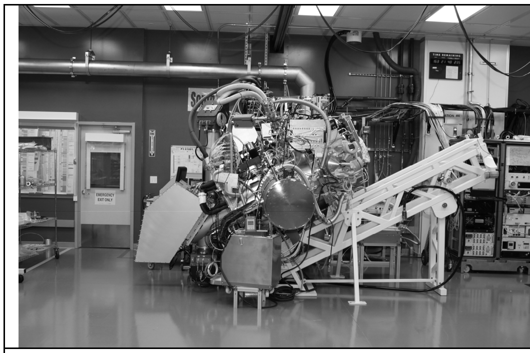

Figure 2: Photograph of a HVM I LPP Source Vessel in production.

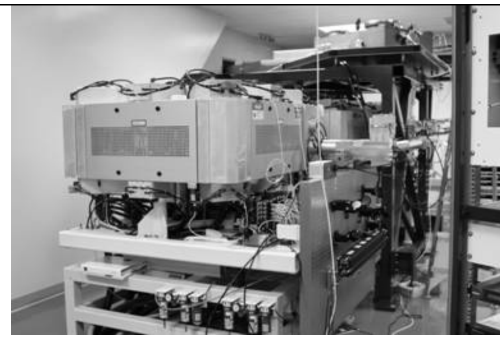

Figure 3: Photograph of a HVM I LPP Source CO_2 Drive Laser in production.

3. RECENT DEVELOPMENT RESULTS

Figure 4 shows the raw EUV power obtained at our Engineering Test Stand LPP source[7] running at 80% duty cycle, as determined from measurements at plasma. IF-equivalent average powers above 90W were reached using standard assumptions of 50% reflectivity for a 5 sr collector and for 90% optical transmission from plasma to IF. The power level was reached using a laser configuration with longer gain length compared to our standard production system and demonstrates the expected performance of the planned upgrade to HVM I sources. The open loop energy stability of a 10ms sliding window through the raw data is 5.4% (3σ) is also shown. An estimated EUV power of 80W will be achieved by applying closed-loop dose control. These experiments were performed using tin droplets with 30 micron diameter at 50kHz repetition rate and 400ms burst duration, the standard production system parameters for our HVM I sources.

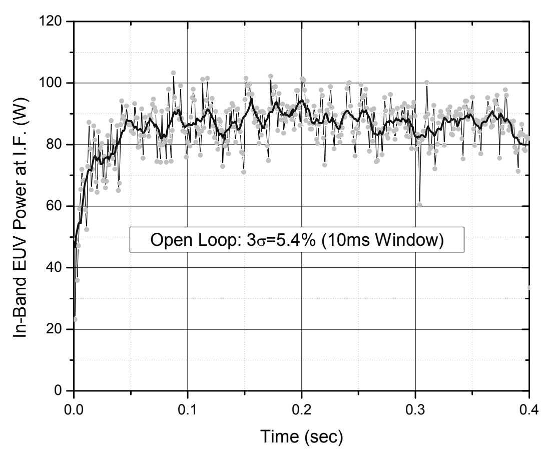

Figure 4: ~90W raw EUV Power at IF obtained in a 400ms burst at 80% duty cycle on 30μm diameter Sn droplets.

Figure 5 and Figure 6 show views of our prototype LPP system integrated with a test fixture in the cleanroom at our customer. This full-size prototype LPP source with basic controls was built in 2008 and shipped in 2009. It was operated in our San Diego facility for about nine months before being transferred to the customer. The maximum EUV power produced on this source was ~45W at IF. Our debris mitigation technology using hydrogen buffer gas was validated on this system using a 5sr collector. The installation at ASML took about three months and the source became operational in September 2009. It has been used for numerous functional tests and integration operations in the months since, including testing of the SPF and its ability to filter out of band IR light. The primary use of the source has been for testing sensors, controls algorithms and interfaces, and diagnostics. Its typical performance as installed is ~10W raw EUV power at IF and ~7W when under dose control (~1.0% stability). The plasma position stability has been measured to be within the specification of ±10µm when under feedback control. The far field EUV intensity distribution from the source has been monitored using a diagnostics tool inserted into the optical path beyond IF.

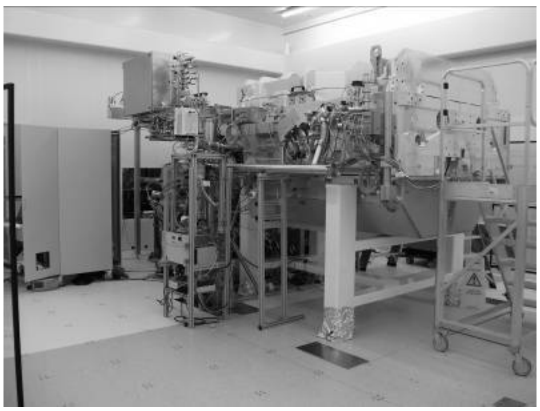

Figure 5: Mid frame vessel housing illumination optics.

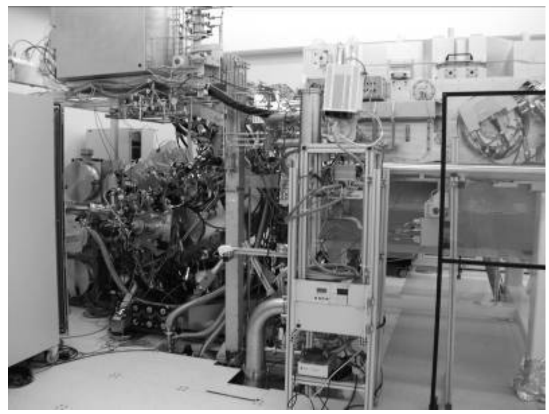

Figure 6: Prototype LPP source integrated with the mid frame vessel.

4. ELECTRICITY CONSUMPTION

A major utility for the EUV source is the electrical power that the system requires. With the operation of the EUV source at nominal scanner operating conditions, we can estimate with reasonable certainty the amount and cost of the electrical power used. These calculations are shown in Table 1. The roadmap for additional EUV power actually predicts a decreasing cost of electrical consumption. Despite higher throughput tools and greater EUV power, this decreased cost is obtained by the more efficient utilization of the available EUV light. A reduced percentage of source on-time is required for the exposure as the duty cycle of the source is reduced, resulting in a lower usage of electrical consumption and a lower cost. It should be noted that the cost of electricity consumption used here was based on 0.09 $/kWhr. Compared to a 193nm immersion light source such as Cymer's XLR 600ix with a power consumption of 85kVA the LPP EUV source consumption is approximately three times greater for equivalent throughput.

	193nm (XLR 600ix)	**EUV (HVM I)**	**EUV (HVM II)**	**EUV (HVM III)**
Source Output Power, Clean EUV (W)	60	100	250	350
Duty Cycle (%)	26%	73%	39%	31%
Source Input Power, Electricity (kVA)	85	448	321	292
Cost of Electricity ($/kWhr)	0.09	0.09	0.09	0.09
Cost of Electricity ($1000/yr)	47	247	177	161

Table 1: Estimated usage and cost of electrical power.

5. ROADMAP

Currently, our HVM I sources are undergoing acceptance testing. HVM I source designs are based on the learning obtained from prototype sources and technology developed on our internal Engineering Test Stand. The LPP source roadmap is shown in Table 2. The HVM I product is expected to meet requirements for pre-production or beta generation scanners in 2010 with clean EUV output powers of >100 W using a 25 kW CO_2 laser system on Sn droplets with 3.0 % CE. The normal-incidence collectors used have a collection solid angle of ~ 5 sr and multilayer coatings with EUV reflectivity > 50 % on average over the surface. Transmission losses due to absorption and debris mitigation techniques are projected to be less than 20 %. It is expected that requirements for later generation LPP EUV sources will drive source powers above the 350 W level (HVM III) with CO_2 laser technology delivering ~37 kW of power. Further improvements in CE and collection efficiency are expected to enable clean EUV power levels exceeding 400W at IF.

EUV Source Power Roadmap			
	HVM I	HVM II	HVM III
Drive Laser Power (kW)	**25**	**35**	**37**
In-band CE (%)	3.0	3.5	4.0
Collection Efficiency (sr)	5	5.5	5.5
Collector Reflectivity (%)	50	50	50
Clean EUV Power (W)	**>100**	**>250**	**>350**

Table 2: Projected LPP EUV source roadmap

6. SUMMARY

Laser-produced plasmas have been shown to be the leading source technology with scalability to meet requirements from leading scanner manufacturers and provide a path toward higher power as the lithography tools evolve over their life cycle. EUV power exceeding 90W at intermediate focus at 80% duty cycle and 400ms burst length has been reported. Normal-incidence collector mirrors of diameter > 650mm, with > 5 sr light collection and average reflectivity >50% are produced and integrated into production LPP systems. The high-conversion-efficiency combination of 10.6 µm laser light and Sn source element has been demonstrated with CE in excess of 3 %. LPP source technology with power levels exceeding 400W is expected to satisfy the IF power requirement projected in the future, and to provide margins for changes in photoresist sensitivity, spectral purity filters transmission, and overall scanner transmission. Cymer intends to commercialize EUV light sources in 2010.

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